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SciVerse ScienceDirect
Energy Procedia 19 (2012) 15 – 22
Energy Procedia

Modelling Of the Behaviour of Solar Cell under High Injection Effect Conditions

Khalaf AL ABDULLAH and Bashar BAKOUR
Laboratory Of microelectronic –University of Aleppo-Faculty of Electrical and electronic Engineering –Aleppo-Syria

Abstract:

An I-V characteristic measurements of silicon solar cell were carried out, the result showed a saturation of open circuit voltage V_{oc} when sunlight concentration reaches 7 suns in our case, which imposed a limitation on the solar cell's efficiency.
For understanding the carrier's transport mechanisms in the cell, a simulation of solar cell behaviour under sunlight concentrating –up to 25 suns- has been carried out.
The minority carrier concentration profiles in the silicon solar cell's base were represented, by solving the continuity equation via suggesting a mathematical sample.
The results enable us to disputes high injection effect at which tacks place when a high concentration of minority carrier -comparable to majority carriers- is appeared in thin area beside the depletion region.

Keywords: Silicon Solar Cell; Open Circuit Voltage; Sunlight Concentration; High Injection Effect;

1. Introduction

Solar cell is a device in which converts incident sunlight power into electricity power, but production of electricity with this manner still costly.
To achieve serious cost reduction of photovoltaic systems, an increasing of their output power per cm^2 is took place by concentrating the incident sunlight onto cell's surface.
High level of illumination leads to degrade performance of solar cell due to two basic effects: first effect is the increase in the operating temperature of the cell, so a cooling system is introduced [1], second effect is increasing of the minority carriers' density to become of the order of the thermal equilibrium value of the majority carriers' density, so, high injection phenomena arises and the fundamental physical processes of carrier transport in the solar cell are altered, where the rate of recombination processes increase due to carriers concentration's increasing at the solar cell's junction on both its sides and losses increase.[2]
In this research we carry out an I-V characteristic measurements of TRi type silicon solar cell under sunlight concentration up to 21.3 suns the cell has these specifications: the doping concentration of the p-region is around 10^{15} cm^{-3}, the emitter layer is heavily doped (around 10^{18} cm^{-3}), and the back surface

 doi:10.1016/j.egypro.2012.05.177

with metal contact, then we simulate the behaviour for this cell to illustrate the distribution profile of minority carriers in the base to understand the behaviour of solar cell when operates in high injection conditions.

2. Background

In semiconductors the time in which carriers stay free before recombine is called lifetime τ, and it is the most important parameter for characterizing the performance of an operated semiconductor devices.
In n^+-p silicon solar cell the minority carriers (electrons) lifetime τ_n is generally defined by the equation:[3]

$$U(x) = n(x, t)/\tau_n \qquad (1)$$

U(x): the rate of recombination carriers
n(x, t): density of excess minority carriers
There exist a several ways in which the pair electron-hole can recombine: [4]

- band to band irradiative recombination
- band to band Auger recombination
- trap assistant recombination

The recombination rate for all the previous ways is a function of the carrier density in the device.
It could express the distribution of excess minority carriers profile by the continuity equation:

$$D_n(d2n/dx^2)+\mu_n E(x)(dn/dx)-(n/\tau_n)+g(x)=0 \qquad (2)$$

Where: D_n, μ_n, E(x), τ_n, g(x), are respectively: the diffusion constant of electron, the mobility of electron, the electric field, the life time of electron and the generation rate of charge carriers due to incident sunlight on the solar cell.
The light generation rate g(x) is usually expressed as a sum of individual waveband contributions over the whole solar spectrum and represented by: [5, 6]

$$g(x)=\sum_{i=1}^{3} C\, a_i \exp(-b_i x) \qquad (3)$$

Where: C is the number of suns, the coefficients a_i and b_i are taken in the AM1 illumination, and the continuity equation becomes:

$$D_n(d2n/dx^2)+\mu_n E(x)(dn/dx)-(n/\tau_n)+\sum_{i=1}^{3} C\, a_i \exp(-b_i x)=0 \qquad (4)$$

It is a second order differential equation and represents the distribution of excess minority carrier profile in the base.
Taking into account an n^+-p silicon junction uniformly illuminated, and the back surface is situated at x-h with a recombination velocity S_b, so the boundary conditions is:[7]

At the interface: $$n(w_p)=n_i^2/N_A[\exp(q\, V_j /KT)-1] \qquad (5)$$

And at back face of the solar cell: $-D_n(dn(x)/dx)|_{x=h}=S_b n(x)|_{x=h}$ (6)
Where:
n_i: the intrinsic carrier density
N_A: acceptor impurity density in p region
S_b: recombination velocity at the back surface
h: wide of the p region
V_j: the junction potential, where is dependent on the operated conditions and defines the minority carriers concentration at the junction boundary.
I-V characteristics of solar cell can be described by the Following double-exponential model: [8]

$$I=I_{ph}-(V_d/R_{sh})-\sum_{i=1,2} I_{oi}(exp(B_i.V_d)-1) \quad (7)$$

Where: $V_d=V+I\ R_s$, $B_1=q/KT$,$B_2=B_1/2$
In addition: I_{ph} , R_s, R_{sh}, I_{o1} (i= 1), and I_{o2}(i=2) are the : photocurrent by incident photon on solar cell, series resistance , shunt resistance, the reverse and dark saturation currents respectively.
Studies showed the relationship between increasing of I_{recom} –who represent the recombination current in depletion region - and each of I_{02}, V_{oc}, w, and solar cell's efficiency under high injection conditions as follow: [9]

$$I_{recom}=I_{o2}.[exp(qV_d/2KT)-1] \quad (8)$$

And: [10] $$V_{oc}=(KT/q)\ ln((I_{ph}/I_0)+1) \quad (9)$$

Where; $K=1.38x10^{-23}$ $j.k^{-1}$, T=300°k, I_0: reverse Saturn current

And: [3] $$I_{recom}=q.n_i.w/(\tau_p.\tau_n)^{1/2} \quad (10)$$

Where; W,τ_p,τ_n. are the depletion region width, Time life of the hole and electron respectively.

And: $$\eta= (FF.I_{sc}.V_{oc})/P_{in}.A \quad (11)$$

Where; FF, I_{SC} , P_{in}, A are : Fill factor, Short circuit current, Incident sunlight power (watt/m^2) and the Solar cell area (m^2).
So, the increasing of I_{o2} leads to the increasing of I_{recom} (eq.8) which leads in its turn to decreasing of Voc (eq.9). In consequently, the diminution of V_{oc}, leads to the degradation of solar cell efficiency η (eq.11)
According to [11], the reason of increasing recombination current 'I_{recom} ' in depletion region when sunlight concentration 'C' increase, is due to the depletion layer widen because the increasing of drift electric field at the junction boundary correspond to population inversion phenomena which happens at the interfaces between the base region and the depletion region.

3. Results

3.1. Measurements

The measurements were carried out under the range (1-21.3) suns of sunlight concentration.
Drawing I_{SC}-C characteristic, (fig.1) showed that I_{SC} proportional to C, while V_{OC}-C characteristic, (fig.2) showed a degrading of open circuit voltage begins at 7 suns concentration, this is due to high injection effect, which imposed a limitation on the expected solar efficiency.

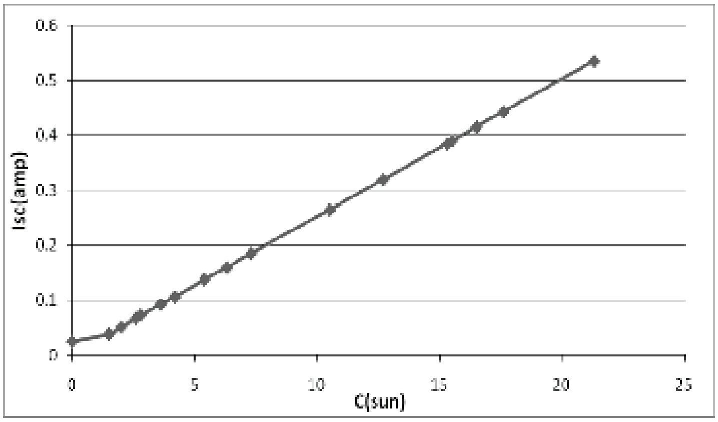

Fig.1 I_{SC}-C characteristic

Fig.2 V_{OC}-C characteristic

3.2. Simulation

In order to characterize the behaviour of silicon solar cell under sunlight concentration, a simulation of minority carriers distribution n(x) (cm^{-3}) along the base wide x(cm) of n^+-p solar cell was carried out by solving the continuity equation (equ.4) with the boundary conditions (equs.5,6) using RUNG KUTTA method – MATLAB program.

The simulation was performed under variation in each of: operation condition (sunlight concentration C, junction voltage V_j), and structural parameters (acceptor impurity density N_A, recombination velocity at the back surface S_b), taking into account the following parameters: [12]

i=1…3

$a_1=6.13x10^{20}cm^{-3}.sec^{-1}$, $a_2=0.54x10^{20}cm^{-3}.sec^{-1}$, $a_3=0.991x10^{20}cm^{-3}.sec^{-1}$.

b1=6630cm, b2=1000cm, b3=130cm.

$D_n=34.91cm^2.sec^{-1}$,$\tau_n=4x10^{-6}$ sec, $q=1.6x10^{-19}$coul, $k=1.38x10^{-23}$ $j.k^{-1}$, T=300°k, $\mu_n=1500$ $cm^2.v^{-1}.sec^{-1}$.

3.2.1. Variation of sunlight concentration C

In this case we'll change C in the range (1-25) suns, so we get on Fig.3

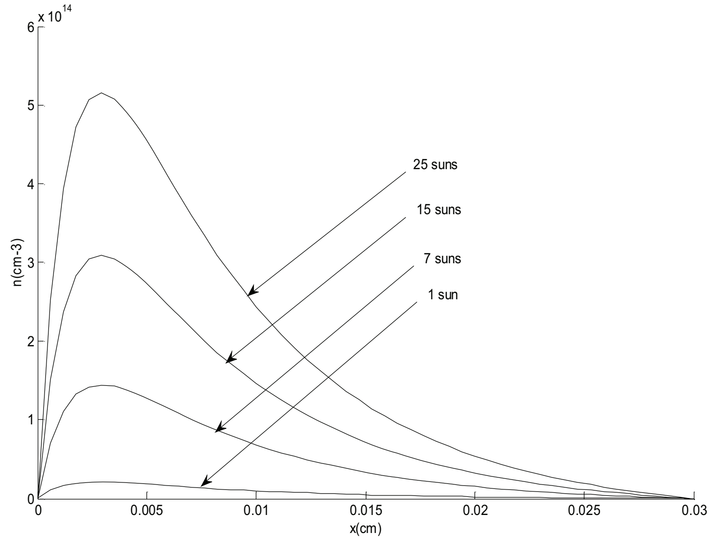

Fig. 3 Minority carriers' distribution along the base of solar cell for several sunlight concentrations where: V_j=0.45v; $N_A=10^{16}cm^{-3}$; h=0.03cm; $S_b=10^5 cm.s^{-1}$

3.2.2. Variation of junction voltage V_j

In our simulation V_j was altered along the range (0-0.6) v, then we get on Fig.4

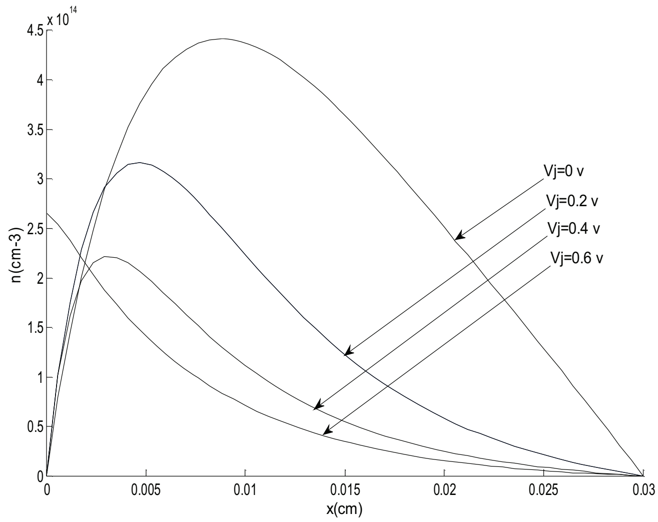

Fig. 4 Minority carriers' distribution along the base of solar cell for several junctions potential value where: C=10 suns; $N_A=10^{16}cm^{-3}$; h=0.03cm; $S_b=10^5 cm.s^{-1}$

3.2.3. Variation of acceptor impurity density N_A

For N_A we choose the following value ($3x10^{13}$, $5x10^{13}$, 10^{14}, 10^{15}) cm^{-3}, and the result of the simulation in this situation illustrate in Fig.5

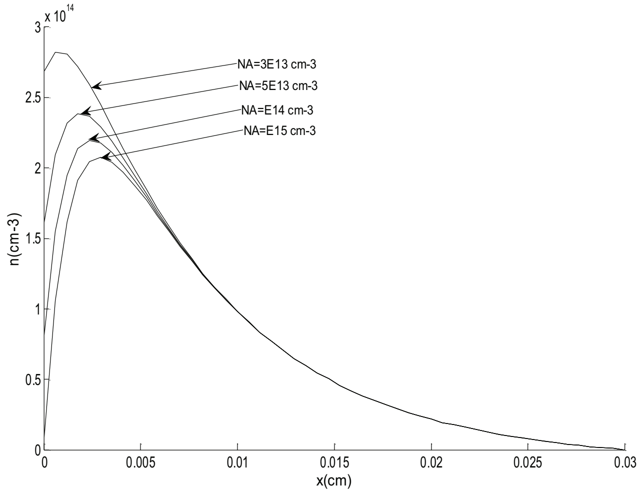

Fig. 5 Minority carriers' distribution along the base of solar cell for several acceptor impurity density value where: C=10 suns; V_j=0.45 v; h=0.03cm; $S_b=10^5$cm.s^{-1}

3.2.4. Variation of recombination velocity at the back surface S_b

In this case S_b was altered by the following value ($1x10^2$, $5x10^2$, $1x10^3$, $5x10^3$) cm/s and the result of the simulation in this situation illustrate in Fig.6

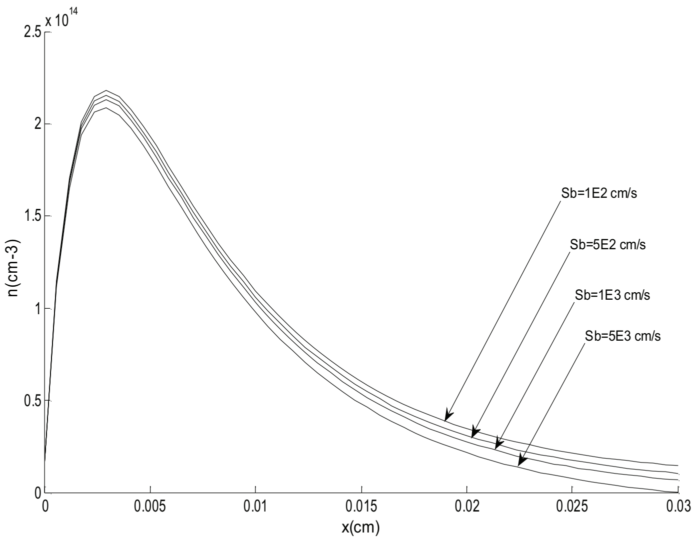

Fig. 6 Minority carriers' distribution along the base of solar cell for several recombination velocity value at the back surface where: C=10 suns; V_j=0.45 v; h=0.03cm; $N_A=5x10^{14}cm^{-3}$

4. Discussion

According to simulation results in the previous cases, we can remark:

4.1. In case of C variation

High injection effect is a phenomenon which happened under sunlight concentration when the minority carriers concentration become larger than, or of the order of the majority carriers concentration (the doping level N_A of the p-type base).
According to the distribution of minority carriers along the base (our simulation), we find that:

1- The high injection effect appears in a then area near the junction, and this area widens more and more as the sunlight concentration increases. Fig. 3

2- The density of minority carriers become of the order of majority carriers (high injection phenomena), when the sunlight concentration reaches the value 7 suns nearly, and this is in agreement with the measurement results, so we can emphasis that the high injection phenomena is responsible of V_{oc} degradation.

4.2. In case of V_j variation

The curves of distribution of minority carriers in this case, Fig.4, shows diminishing of the carriers density and curves displacement towards the junction as the junction voltage V_j increasing, this is due to the increasing of positive polarization at the other side (n side) of p-n junction which traps the electrons (minority carrier charges) from the p region, and growth of base-emitter coupling current.
At the other hand, the curve in which V_j=0.6v, shows a retrogression of the carries from the junction-base interface to the back surface, (by other word: accumulation of the carriers at the junction – base interface), and this is can be explained by the domination of open circuit voltage condition V_{oc} theoretically, which mean there is no load at cell terminal, and no base-emitter coupling current, but we note that the minority carriers density curve at V_j=0.6v is diminished comparing to other curves, so we suppose the reason relate to high injection effect and this is in agreement with our interpretation in [11], which include:" the increasing of minority carrier, n_p, recombination current 'I_{recom} ' in depletion region when sunlight concentration 'C' increase, is due to the depletion layer widen because the increasing of drift electric field at the junction boundary correspond to population inversion phenomena which happens at the interfaces between the base region and the depletion region".

4.3. In case of N_A variation

From Fig.5, we can see that the curves of distribution of minority carriers is diminished as the acceptor impurity density N_A increases, and this is can be explained by: as N_A decreases , high injection condition can be reached faster.

4.4. In case of S_b variation

In this case, no serious influences of variation of recombination velocity at the back surface S_b on the curves of distribution of minority carriers close to the junction region.

But these influences clearly appear near the back surface at the range (0.02-0.030) cm, which the carriers density increase as S_b decrease and this is can be explained by: the back surface acts as a mirror for carries when S_b decrease.

5. Conclusion

We introduce a study of the behaviour of silicon solar cell under high injection effect condition by suggesting a simulation, which describe the distribution of minority carriers' density along the base under variation of each of operation conditions (C, V_j) and structural parameter (N_A, S_b).
Results of this simulation showed an agreement with measurement results, in which enable us to characterize the solar cell behaviour when the sunlight concentration reaches the value 7 suns and the high injection phenomena arise.

References

[1]. D.J. Mbewe, H.C. Card and D.C. Card, Solar Energy, 35, 247-258 (1985).
[2]. M.A. Green, IEEE Trans. On Electron Devices, ED-31, 671-678 (1984).
[3]. S.M. Sze, 'physics of semiconductors devices' Wiley, New York, (1981).
[4]. S.T. Sah and F.A. Lindholm, IEEE Trans on Electron Devices, 24(4). 358 (1977).
[5]. J.Furlan and S.Amon, Solid-State Electronics. 28(12), 1241 (1985).
[6]. S.N. Mohammed, J.Appl.Phys. 61(2), 767 (1987).
[7]. F. PELANCHON, S.MOUHAMMAD, 'carrier distribution and high injection in semiconductors' Conference signals & systems, AL-Ain (U.A.E) JAN 29-31, AMES press, vol, 4, pp.3-10, (1990).
[8]. P. MIALHE, S.MOUHAMED, A.HAYDER, F.PELANCHON, 'the dember effect in the base of a solar cell' congress of the international solar energy society, vol.1, p. 127-131, (1989).
[9]. B.Bakour. "Optimal Study Of The Performance Of Small Size Solar Cell", Thesis Submitted for Ph.D Degree, 2010.
[10]. D.H. Navon, 'Semiconductor Microdevices and Materials' CBS College Publishing, New York, (1986).
[11]. K. Al-Abdullah, B. Al-Bakour "Influence of depletion region width on performance of solar cell under sunlight concentration" The Energy Procedia journal (Elsevier-Science Direct), vol.6, (2011), p.36-45.
[12]. F. PELANCHON, S.MOUHAMMAD, 'carrier distribution and high injection in semiconductors' Conference signals & systems, AL-Ain (U.A.E) JAN 29-31, AMES press, vol, 4, pp.3-10, (1990).